

DETERMINATION OF AN ACHIEVABLE MATERIEL AVAILABILITY FOR THE JOINT AIR-TO-GROUND MISSILE



James C. Byrd and Michael “Mike” J. Osborne

When Am (Materiel Availability), which marks a significant departure from Ao (Operational Availability), was established as a fleet-level Key Performance Parameter (KPP) by Joint Requirements Oversight Council Memorandum 161-06, issued by Navy Admiral Edmund P. Giambastiani on August 17, 2006, the Joint Attack Munitions Systems (JAMS) Project Office Logistics Directorate was tasked to develop a viable Am threshold and objective Am KPP for the Joint Air-to-Ground Missile (JAGM) system. This article describes the thought process and analyses that resulted in the JAGM Am KPP contained in the JAGM Capability Development Document (CDD) and system specification. The cause and effect relationships between logistics activities as well as the pros and cons of the application of Am to the JAGM system are discussed.

Keywords: *Materiel Availability, Key Performance Parameter, Performance-Based Logistics, Key System Attribute*

Concept image rendering, not actual missile.

JAGM

Joint Air to Ground Missile



On August 17, 2006, Joint Requirements Oversight Council Memorandum (JROCM) 161-06 (Giambastiani, 2006) approved the *Key Performance Parameters* (KPP) Study recommendations and endorsed the implementation of a mandated *Materiel Availability* (Am) KPP. This memorandum also mandated the implementation of materiel reliability and ownership costs as supporting *Key System Attributes* (KSA). These mandates apply to all Major Defense Acquisition Programs (MDAP). The Deputy Under Secretary of Defense for Logistics and Materiel Readiness (DUSD L&MR) issued a policy memorandum establishing four materiel readiness outcome goals for all Acquisition Category (ACAT) I acquisition programs (DUSD L&MR, 2007). This list included all mandates contained in JROCM 161-06 and defined Mean-Down-Time (MDT) as an additional KSA as well as 14 life cycle sustainment *enablers*. On March 1, 2009, the Chairman of the Joint Chiefs of Staff (CJCS) (2009b) released CJCSI 3170.01G, which provided guidance on the development of KPPs. Am is defined as “a measure of the percentage of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given point in time based on materiel condition” (Chairman of the Joint Chiefs of Staff, 2009a, p. GL-15). It is expressed as:

$$\frac{\text{number of end items operational}}{\text{total population of end items}}$$

The formula yields the percentage of end items that are Fully Mission Capable (FMC) at the time of the measurement.

APPLICABILITY TO JOINT ATTACK MUNITIONS SYSTEM (JAMS)

The initial JAMS response to the mandate to add the requirement to the JAGM CDD was to request an exemption. The Program Office rationale seemed straightforward since missile products are unique given that tens of thousands of spare end items are available in depot storage for issue upon demand. Given that the JAGM missile is a certified round with no field maintenance, there is no forward maintenance downtime.

After missiles are expended, aircraft are reloaded; replacement inventory is then requisitioned and issued from the Ammunition Supply Points (ASP). ASPs would requisition replenishment rounds from the depot storage sites. This volume of inventory made it possible to provide near 100 percent Am at the unit level. It was therefore proposed by the JAMS Program Office that the materiel reliability KSA might satisfy the Am KPP requirement. This request was quickly denied. The rationale for the denial related to the actual definition of Am was as follows: “The materiel availability addresses the total population of end items planned for operational use, including those temporarily in nonoperational status once placed into service, [such as depot-level maintenance]” (Chairman of the Joint Chiefs of Staff, 2009a, p. B-B-3).

The JAMS Program Office therefore shaped the Am analysis to include repair/maintenance time, logistics time, depot turnaround-time, transportation

time, system Operating Tempo (OPTEMPO) retrograde evacuation time, transit quantities, and total end item inventory into the MDT mix.

RAMIFICATIONS OF MATERIEL AVAILABILITY TO JAMS

Am (Materiel Availability) is a significant departure from Ao (Operational Availability), which is an analysis that provides a probability of success based on the average of the key element—downtime—over a specified period of time. Ao is measurable during demonstration testing (Department of Defense, 1982), but once fielded, data collection and Ao validation are not possible since not all elements of downtime are a unit-reportable requirement. Am, on the other hand, is the measure of the percentage, not probability, of the total FMC systems at any given point in time. Interestingly, Am is not measurable during Logistics Demonstrations or Independent Operational Test and Evaluation (IOT&E) events because the key player in the Am algorithm—the supply chain parameter component of MDT—does not yet exist. Instead, key components of Am are approximated against reasonable estimates of external factors such as the supply chain.

Although not intuitively obvious, it became clear that the JAMS Program Office needed to assume control of what constituted an achievable Am that could be included into the CDD, as opposed to a mandated Am. The achievable Am baseline is the result of product and support design specifications and analysis of controllable and uncontrollable circumstances to define threshold and objective Am metrics. This analysis must be performed by the developer and must be submitted and defended by the materiel development command. Delegating this responsibility to the developing command drives the materiel developer to consider all elements of Am and examine element interaction in order to arrive at an achievable and defensible Am requirement to include in the CDD.

RESULTS

INITIAL FINDING

Am results will be necessarily lower than Ao analysis results (apples versus oranges) since Am encompasses *all* elements of downtime across the entire system population. Instead of attempting to measure an Ao probability by collecting actual downtime to arrive at Mean Time between Failures (MTBF) and Mean Time to Repair (MTTR), the Am algorithm must be dissected into its basic components for analysis.

Examining each MDT component's contribution to downtime allows the materiel developer to identify and focus on controllable components that define early supportability, producibility, durability, and reliability design criteria during the technology development and system development and demonstration phases of the program (Assistant Under Secretary of Defense [Materiel and

Readiness], 2004). These derived design criteria must be included in the system specification and form the basis for Performance-Based Logistics (PBL) metrics included in performance-based agreements and ultimately into support contract language. Am therefore forces the materiel developer to consider both the acquisition and sustainment phases of the life cycle in a deliberate design effort to compress MDT while minimizing the frequency, duration, and cost of support elements.

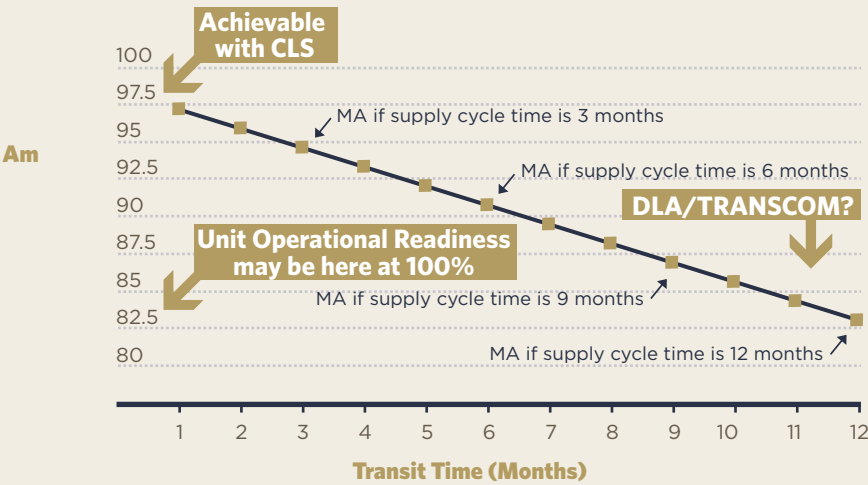
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From the materiel developer perspective, Am components can be grouped into two fundamental categories: controllable and uncontrollable.

Controllable components are those that are within the control of the materiel developer and are the only components that the developer can influence in reducing MDT. These components are reliability, maintainability, maintenance turnaround time, repair/maintenance time, logistics time, and depot turnaround time. Reliability is a KSA minimum value that is included in the CDD as a derivation from stated user requirements and is used in the algorithm to determine achievable Am. The remaining elements are key-design components for reducing MDT, and their value must be optimized and included in the system specification in order to cost effectively maximize Am. Although depot turnaround time is difficult to quantify if the system is in the Technology Demonstration phase (pre-Milestone B), it is an obvious PBL metric candidate for inclusion in the support section of the production contract or the Contractor Logistics Support (CLS) Statement of Work. Less obvious perhaps is the effect of transitioning from tightly controlled contractor supply chain turnaround times (TAT) under a CLS concept to an organic support or partnerships scenario. CLS supply chain TAT efficiency is a combination of detailed specification requirements and the contractor's desire to meet applied TAT metrics (use of FedEx, DHL, etc.). Supply chain variances emerge under organic support, which are out of the control of the program office. These variances, when negatively impacting both supply chain timelines and depot TAT, cause Am to degrade when the transition occurs.

Uncontrollable Am components include OPTEMPO, transportation time, and retrograde evacuation time. Transportation out of theater retrograde, which can be a low priority, will vary depending on the mode and frequency of trips. Missiles in particular cannot be shipped commercially (FedEx, DHL etc.), but only through government transportation nodes, which causes wide variations in the missile retrograde times. These components are out of the control of the developer and are driven by policy and the transportation infrastructure. Assuming a range of transportation times from 1 to 12 months, modeling analysis demonstrated the effect on Am as illustrated in Figure 1.

FIGURE 1. TRANSIT TIME IMPACT ON AM



Am can be anywhere between 98% and 82% with no effect on fill rate at demand point.
Spares drawdown is from storage.

SECOND FINDING

Upon this initial analysis, the JAMS Logistics Directorate concluded that the only logical approach to implementation was to model component relationships in order to target meaningful Am values. This required collecting hard OPTEM-PO data, depot experience data from other related programs, and analysis of design attributes of similar systems. Reasonable assumptions were made to fill in the data gaps. These data were rolled into a simple model that provides the resulting Am given a set of inputs, as well as providing values of key data points of interest. This resulted in an achievable and defensible Am value to include in the CDD.

Because Am is not testable during Logistics Demonstrations or IOT&E events due to the absence of the supply chain component of MDT, the Army Test and Evaluation Command (ATEC) contacted the JAMS PO to discuss implementation approaches. ATEC had come to the same conclusion as the JAMS PO—that modeling and simulation was the only logical approach—and requested that we provide our model to them as a starting point for their modeling and simulation efforts. Details of the JAMS Am analysis are discussed in ensuing paragraphs.

Munitions uniquely differ from more traditional systems because although ships, aircraft, and ground vehicles may be destroyed in performing their mission, a successful munitions mission *always* results in its destruction. In addition, high volume expenditure rates during wartime operations such as Operations Iraqi Freedom and Enduring Freedom (OIF and OEF) create significant inventory fluctuation over time. How would this impact Am over time? It was therefore determined that a period of interest must be included in the Am analysis algorithm.

Collection of operational data for reliability and maintenance analysis was also an issue. Classic reliability is expressed as the probability that a system will successfully complete its mission for a specified duration. The reliability of JAMS products such as HELLFIRE is expressed as the probability of a successful engagement for a defined period of on-wing time or captive carry time. This captive carry limit is known as *durability*. For example, a durability limit of 100 hours means that the reliability of the round decreases when captive carry time exceeds 100 hours. This clock begins when a factory fresh round is installed on

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an aircraft in operational service. Just as nonmunitions systems require periodic maintenance to maintain system reliability, so does the missile. During current wartime operations, this is called Reset. Because JAMS munitions are typically certified rounds, they are not maintained in the field and must be returned for depot maintenance. Current munitions design does not include a mission clock, which is partially due to technology limits during the period of development, but also due to conservative expectations. Original estimates assumed that no missile would be on-wing longer than the durability requirement. Operations in Bosnia gave us a glimpse that this might not be the case. OIF and OEF confirmed this with captive carry times exceeding durability limits by almost 1,000 percent. In response to this, the JAMS PO is developing Health Monitoring Units (HMU) to be installed in the round with an external indicator to display key operational data. This will soon undergo limited field testing. In the interim, JAMS has deployed depot maintenance technicians to the field tasked to collect and report this data. These factors are important to the Am calculations. Exceeding the durability limits negatively impacts Am through a reduction in materiel reliability (KSA), and returning the munition to the depot also decreases the Am by removing it from the total operational population. Lastly, there is the challenge of considering operating at a reduced reliability to offset the negative impact on Am by removing the unit from service. These kinds of issues illustrate Am's influence and are clearly optimization problems, pitting cost and performance against Am requirements.

The uniqueness of the munitions system caused several assumptions to be made in order to bound the analysis within a relevant range and stabilize inherent dynamics associated with design, operations, and policy. The following assumptions also simplified our approach, which was critical in meeting a short suspense:

- The analysis models missile availability based on aircraft operations.

- Based on a two-level maintenance concept, Unit (pass/fail Built-in-Test (BIT), remove and replace) and Depot only.
- First-in-first-out: Expenditures consist of the highest captive carry times.
- The scrap rate is calculated against maintenance pipeline.
- This is a steady state model. All inputs remain static for the period of interest.
- Stockpile surveillance is assumed to occur once annually with a sample size of 10 percent.
- Transit time is bi-directional, both to and from the depot.
- Depot MTTR does not include touch labor or time associated with batch processing of missiles such as paint and curing time.
- Reset was included in this model due to current events—missiles exceeding durability limits during OIF/OEF.

The modeling process was straightforward. Operations and Support (O&S) data and reliability requirements were modeled to derive the annual volume of maintenance, which is expressed as the MDT pipeline. This pipeline represents the number of systems unavailable for service, which is the prime factor in calculating Am. Managing this pipeline became the strategy, and the goal was simple: explore viable, cost-effective methods to shorten the pipeline in order to maximize Am. Key controllable components were analyzed to examine their impact. Model algorithms follow:

- STORAGE/TRANS: Total quantity of missiles in stockpile and in transit at any time. Computed as $TOTAL\ MSLS - TOTAL\ EXPENDITURES - ON-WING$
- ON-WING: Total quantity of missiles on-wing. Computed as $A/C\ DEPLOYED \times JAGM\ LOAD\ (\%) \times MISSION\ LOAD$
- ANNUAL MSL OP HRS: Total annual cumulative missile captive carry time. Computed as $MISSION\ LOAD \times JAGM\ LOAD\ (\%) \times A/C\ DEPLOYED \times OPTEMPO \times 12$
- PREFLT BIT FAILURES: Annual quantity of missile BIT failures during aircraft loading operations. Computed as $PREFLIGHT\ BIT\ FAILURE\ RATE \times (ANNUAL\ MSL\ OP\ HRS \div DURABILITY\ RQMT)$
- MTBF: Derived from missile reliability and durability. Computed as $(-1 \times DURABILITY) \div (\text{Log } [MSL\ RELIABILITY])$
- ANNUAL IN-FLT FAILURES: Annual on-wing missile failures during missions. Computed as $(ANNUAL\ MSL\ OP\ HRS \div MTBF) \times (1 - EXPENDITURE\ RATE\ [\%])$
- STOCKPILE FAILURES: Failures discovered during annual surveillance exercise. Computed as $(1 - STOCKPILE\ RELIABILITY) \times .1 \times (STORAGE\ AND\ TRANS - RESET - ANNUAL\ IN-FLT\ FAILURES - PREFLT\ BIT\ FAILURES)$
- TOTAL ANNUAL FAILURES: Total quantity of missiles out of service due to functional failure or exceeding durability limits.

Computed as PREFLT BIT FAILURES + STOCKPILE FAILURES + ANNUAL IN-FLT FAILURES + RESET + SCRAP. SCRAP is computed as SCRAP RATE x RESET

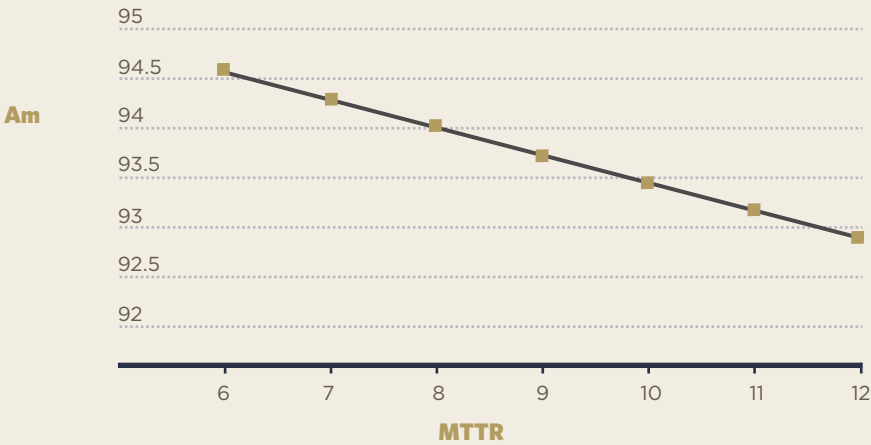
- RESET: Total annual missiles that have accumulated Captive Carry Time beyond the durability limit and must be returned to depot for service. Computed as $(\text{ANNUAL MSL OP HRS} \div \text{DURABILITY RQMT}) - (1 - \text{EXPENDITURE RATE} [\%])$
- TOTAL EXPENDITURES: Total quantity of expended missiles for the period of interest. Computed as $\text{RESET} \times \text{PERIOD OF INT} \times \text{EXPENDITURE RATE} (\%)$
- TOUCH LABOR/MO: Total monthly depot touch labor. Computed as $(\text{TOTAL ANNUAL FAILURES} \div 12) \times \text{DEPOT MTTR}$
- MONTHS BACKLOG: Number of months in depot backlog based on capacity and volume. Computed as $\text{TOUCH LABOR/MO} \div (160 \times \text{SHIFT} \times \text{TEST SETS})$
- QTY IN TRANSIT: Total number of missiles expected to be in transit at any point in time. Computed as $\text{MONTHS IN TRANSIT} \times (\text{TOTAL ANNUAL FAILURES} \div 12)$
- DEPOT WORKLOAD: Total number of missiles in work at the depot at any given time. Computed as $\text{TOTAL ANNUAL FAILURES} \div 12 \times \text{MONTHS BACKLOG}$
- PIPELINE QTY: Total quantity of unserviceable missiles in the maintenance pipeline and serviceable missiles in transit from the depot to storage at any give time. Computed as $\text{DEPOT WORK LOAD} + \text{QTY IN TRANSIT}$
- MATERIEL AVAILABILITY: Percentage total population of end items ready for service at any give time. Computed as $1 - (\text{PIPELINE QTY} \div [\text{INITIAL TOTAL MSLS} - \text{TOTAL EXPENDITURES}])$

MTTR was selected as a key component for analysis since it is a significant piece of the depot repair turn around time. The system is a certified round; therefore, the MTTR is restricted to depot level. The MTTR as defined herein addresses only direct touch labor required to test, fault isolate, and replace failed components. It does not include time processes such as painting, curing, or any processes that are typically batched processed. The definition of this component is specific because it focuses on design for maintainability. This depot maintenance is accomplished using an All-Up-Round (AUR) test set, which is often limited to only one or two sets. This is where the maintenance throughput becomes limited due to nonavailability of test set time, thus creating a bottleneck. This is not uncommon in operations involving high-cost, one-of-a-kind test equipment. The relationship between MTTR and Am is illustrated in Figure 2.

Because the net effect of MTTR was not as significant as expected, the shortest MTTR possible (6 hours) given technical limitations and cost constraints was included in the system specification. Figure 2 shows that a doubling of the MTTR to 12 hours reduces the Am by approximately 2 percent.

Directly associated with MTTR, Direct Labor and Test Equipment were se-

FIGURE 2. MTTR IMPACT ON Am

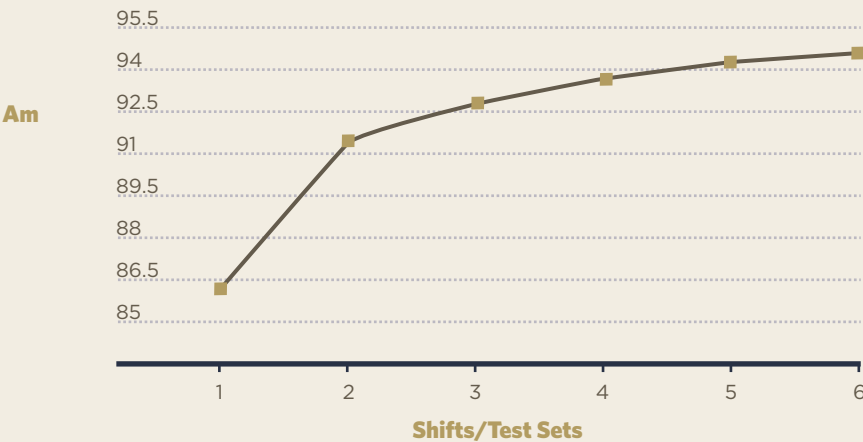


lected. These components represent the number of standard work shifts and quantity of test equipment in operation at the depot. Their effects on Am are illustrated in Figure 3. The numbering along the X axis represents a combination of work shifts and equipment converted into shifts. Additional equipment will not be added until all possible shifts are used. For example, 3 represents 3 shifts per day/5 days per week on 1 test set. Six might represent 3 shifts per day/5 days per week on 2 test sets. There are, of course, possibilities in between that might incorporate underutilized production equipment on a noninterference basis.

While initial gains are significant, returns decline almost leveling off by 6 shifts/test sets. This is due to inventory build up resulting from transit time remaining unchanged. Typical transit time is within approximately 25 percent of depot backlog so the net effect of reducing depot turnaround time diminishes.

Durability is the last of the controllable components with significant effect on Am. Durability was examined rather than reliability because it offered greater improvement within reasonable limits and could be continually improved

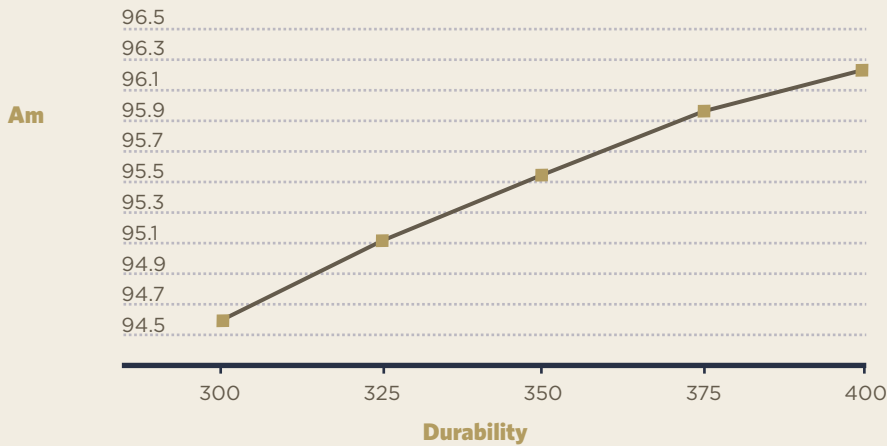
FIGURE 3. DEPOT DIRECT LABOR AND TEST EQUIPMENT IMPACT ON AM



through reliability growth studies during and after development. The JAMS PO is currently requesting the return of high captive carry rounds from theater to study the possibility of extending durability limits. Additionally the fielding of the HMU capability, as previously noted, will provide much needed data in the evaluation of the viability of expanding the durability/captive carry limits, and will provide the data to assess the reliability and service life of the tactical missile stockpile under the Stockpile Reliability Program (SRP). As illustrated in Figure 4, extensions to durability limits can yield significant gains in Am.

FIGURE 4. DURABILITY IMPACT ON AM

The focus from controllable components (within control of the materiel de-

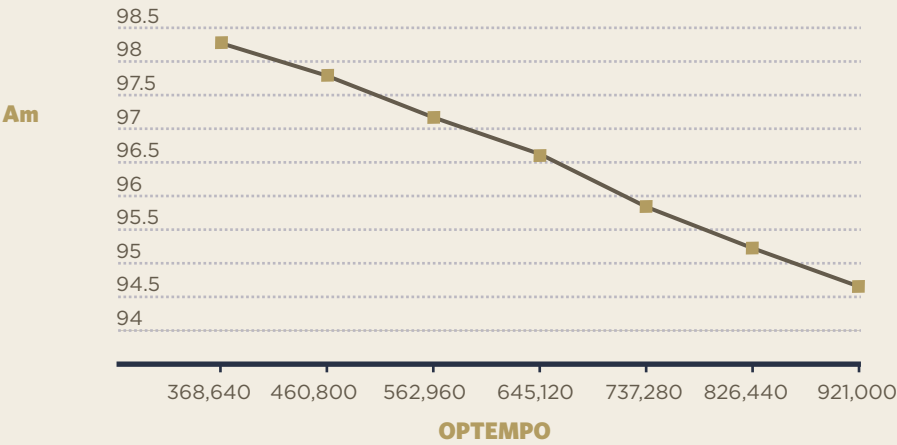


veloper) to those uncontrollable components was the next step. These are the components that were necessarily estimated based on historical experience. These components by their very nature are variable, and it is therefore prudent that the effect of variances in the uncontrollable elements be examined in order to understand the impact to Am caused by events out of the control of the materiel developer and the program manager.

The first to examine is OPTEMPO, which, as it varies, has a significant effect on Am. This component is simply the total annual operating hours accumulated by all rounds in service and is dependent on quantity per platform, platform density, monthly OPTEMPO of the platform, and munitions expenditure rate. Figure 5 illustrates the impact of reducing the platform OPTEMPO by 5 hr/mo increments. The analysis assumed worst case OPTEMPO to ensure that the Am was viable during the most critical need.

Expenditure rate was the most interesting component in the analysis. Surprisingly, the Am increases significantly as the expenditure rate increases. This is due to an effect termed *launching the pipeline*. This essentially means that as the expenditure rate increases, fewer rounds will enter the maintenance pipeline. This is largely due to Reset comprising almost 90 percent of the maintenance volume. If the first-in-first out policy is practiced, then the oldest rounds will be fired first. This essentially leaves preflight BIT failures, in flight BIT failures, and annual stockpile surveillance failures as the only driver for the depot mainte-

FIGURE 5. MISSILE OPTEMPO IMPACT ON Am

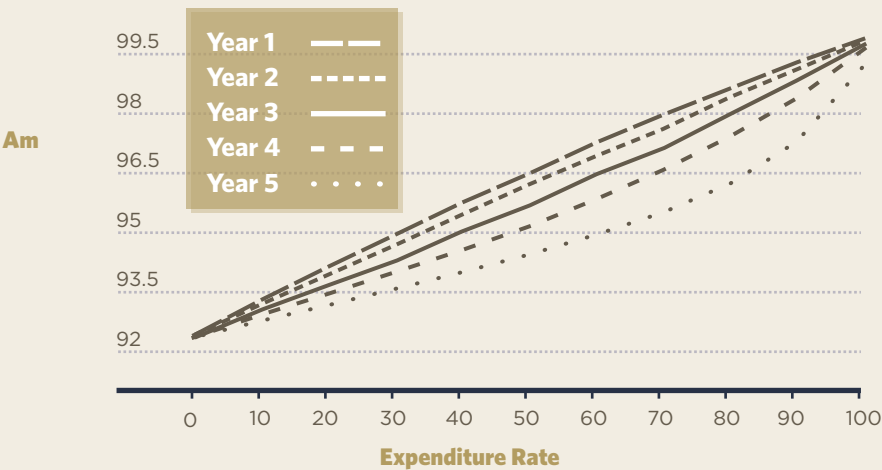


nance workload. As expenditure rates decrease, so does Am. This is primarily due to more rapid accumulation of captive carry hours on in-service rounds that are rarely expended.

The period of interest in years makes little difference. This is due to the reduction in total population by the number of expended rounds. Although the ratio of unserviceable rounds to total population becomes smaller, it is not significant (see Figure 6). By the end of 5 years, the Am at expenditure rates above 50 percent is at or above acceptable levels while inventory levels are almost depleted. Figure 6 illustrates the effect of the expenditure rate on Am.

This points to a weakness in applying Am across the board. For Am to be meaningful in this application, an additional constraint such as a KSA specifying a minimum inventory level would be needed. For example, a minimum inventory level of 10,000 rounds would mean that expended rounds would be deducted from inventory until reaching 10,000, at which time expended rounds would not be deducted but would be counted as unavailable for service. This additional

FIGURE 6. IMPACT OF EXPENDITURES ON Am OVER TIME



KSA would apply to systems such as munitions that experience large, naturally occurring inventory fluctuations resulting from training and combat operations. By tying inventory levels to Am, replenishment quantities could be significantly influenced or possibly totally based on Am. In doing so, production and support contracts could be designed as total PBL agreements where the contractor has the latitude to optimize all PBL elements, including production, to achieve the required Am.

CONCLUSIONS

Much work remains before Am can be totally integrated into requirements development, design, development and support contracting, and ultimately measured. As far as the JAMS PO approach goes, it provided a logical and defensible basis for defining viable Am requirements. This experience has also demonstrated the extent to which Am reaches across organizations and policies.

Implementation of Am also has a direct impact on PBL implementation. A mandate to include a KPP of Materiel Availability in all CDDs for ACAT I programs drives the materiel developer to examine all controllable conditions and define a calculated value for each in the system specification. This in turn allows the materiel developer the opportunity to engage and evaluate the progressing design for sustainment during the Life Cycle Logistics phase of the program, and develop very specific PBL metrics as the PBL planning takes place during the Technology development and System Design and Development stage. Am simplifies PBL in that as Am forces “design for support” to reduce the frequency, duration, and cost of the support elements that affect the Am, there is less of a maintenance burden and infrastructure to consider for the application of PBL principles. PBL contracts can now be managed against Am and cost, allowing the contractor to internally derive contract deliverables required to achieve the required Am metric. This arrangement could give the contractor control of requirements such as repair quantities and inventory levels traditionally retained by the government.

Government agencies such as Defense Logistics Agency, Transportation Command, organic depots, and materiel support commands must become stakeholders in the uncontrollable Am components that they own by implementing PBL concepts designed to respond to system-level requirements rather than their own internal metrics.

Author Biographies



Mr. James C. Byrd is currently the logistics team lead for the Joint Air-to-Ground Missile, the next generation of HELLFIRE and Longbow. His logistics career spans 38 years of experience in all life cycle phases with the Navy, National Aeronautics and Space Administration, U.S. Army Aviation and Missile Command, and commercial programs. Dr. Byrd holds an MBA in Logistics and is a Certified Professional Logistician.

(E-mail address: james.byrd@msl.army.mil)



Mr. Michael "Mike" J. Osborne is a senior program analyst currently supporting the Army Program Executive Office Missiles and Space acquisition and development of an Army/Navy Joint Air-to-Ground missile. He has been a Certified Professional Logistician since 1989, and was re-certified in 2002 by the International Society of Logistics. Mr. Osborne was also certified as a configuration and data manager by National Defense Industrial Association in 2003.

(E-mail address: michael.osborne@msl.army.mil)

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